SOUND ABSORPTION CHARACTERISTIC OF LIGHTWEIGHT BRICK CONTAINING EXPANDED POLYSTYRENE BEADS (EPS) AND PALM OIL FUEL ASH (POFA)

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Dedicated to my beloved family,

En Kamarulzaman bin Abu Bakar,

Pn Norhaizan bt Mohd Noh,

and all my brothers.

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ABSTRACT

The main objectives of this research is to identify the sound absorption characteristic of lightweight bricks containing expanded polystyrene beads (EPS) and palm oil fuel ash (POFA). In order to fulfill the standard of a lightweight brick to be used as a building element, the physical and mechanical properties were test first. EPS was used as a sand replacement whereas POFA was used as a cement replacement. The bricks were casted with 0% to 50% of EPS and 0% to 25% of POFA and air cured for 7, 28 and 56 days. The bricks incorporated with 30%, 40% and 50% of EPS were considered lightweight bricks as they have a density below 1680 kg/m^3. The lowest density recorded for the brick sample with the maximum EPS and POFA content was 1320.52 kg/m^3 after a curing period of 56 days. Bricks incorporated with varying percentages of EPS and POFA have strength values between 3.7 MPa to 21.3 MPa which are acceptable for load bearing and non-load bearing structures. The water absorption values recorded for these bricks were between 4.37% to 13.4%. The brick sample with 0% POFA and 50% EPS recorded the lowest water absorption values while the brick sample with 25% POFA and 0% EPS recorded the highest water absorption values. For the sound absorption test, at high frequency, the brick specimen with 25% POFA and 50% EPS recorded the lowest coefficient of 0.009 while the best sound absorption coefficient recorded was 0.467 for the brick sample with 0% EPS and 10% POFA. At low frequency, the bricks recorded a sound absorption coefficient of 0.89 to 0.998. Most The brick have excellent absorption at low frequency and good absorption at high frequency. Lastly, the density properties and sound absorption coefficient were found to be the most correlated due to the highest R^2 value of 0.9259 compared to other properties.

ABSTRAK

Kajian ini dijalankan untuk mengenalpasti sifat pekali penyerapan bunyi bagi bata ringan yang mengandungi butiran polistrena (EPS) dan abu bahan api kelapa sawit (POFA). Dalam mencapai piawaian bata ringan sebagai bahan binaan bangunan, ujian sifat fizikal dan mekanikal telah dijalankan terlebih dahulu. EPS sebagai gantian pasir dan POFA sebagai gantian simen Portland (OPC). Bata telah dibancuh dengan gentian EPS sebanyak 0% hingga 50% dan gentian POFA sebanyak 0% hingga 25% dan diawet selama 7, 28 dan 56 hari dalam keadaan udara bersuhu bilik. Bata dengan 30%, 40% dan 50% penggantian EPS mempunyai ketumpatan di bawah 1680 kg/m^3 yang dikategorikan sebagai bata ringan. Ketumpatan terendah yang direkodkan ialah 1320.52 kg/m^3 untuk bata dengan gantian 50% EPS dan 25% POFA pada hari ke 56. Bata dengan pelbagai penggantian EPS dan POFA mempunyai kekuatan antara 3.7 MPa hingga 21.3 MPa boleh diguna pakai untuk struktur galas beban dan tanpa beban. Peratus penyerapan air yang direkodkan untuk bata ini adalah antara 4.37% hingga 13.4%. Bata dengan 0% POFA dan 50% EPS mempunyai peratus penyerapan air terendah manakala bata dengan 25% POFA dan 0% EPS mempunyai peratus penyerapan air tertinggi. Untuk ujian pekali penyerapan bunyi, pada frekuensi tinggi, bata dengan 25% POFA dan 50% EPS mempunyai pekali terendah iaitu 0.009. Pekali penyerapan bunyi yang terbaik direkodkan ialah 0.467 pada bata yang mempunyai gentian 0% EPS dan 10%.POFA Untuk frekuensi rendah, bata dapat menyerap bunyi dengan pekali 0.89 hingga 0.998. Nilai ini dianggap sangat cemerlang kerana ia hampir kepada nilai maksimum pekali penyerapan bunyi. Akhir sekali, sifat ketumpatan adalah yang paling berhubungkait dengan pekali penyerapan bunyi adalah kerana mempunyai nilai R^2 yang paling tinggi berbanding dengan sifat yang lain. Nilai R^2 yang diperoleh adalah 0.9259.

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LIST OF SYMBOL ANDS ABBREVIATIONS

ASTM	-	America Standard for Testing and Material
BC	-	Before Century
BS	-	British Standard
BS EN	-	British Standard European Norm
cm	-	Centimeter
CO_2	-	Carbon Dioxide
dB	-	Decibel
EPS	-	Expanded Polystyrene Beads
Hz	-	Hertz
FKAAS	-	Fakulti Kejuruteraan Awam dan Alam Sekitar
g	-	Gram
ISO	-	International Organization for Standardization
kg	-	Kilogram
kg/m^3	-	Kilogram Per Cubic Meter
m^3	-	Cubic meter
ml	-	Milliliter
mm	-	Millimeter
MPa	-	Mega Pascal
MN/m^2	-	Meganewton Per Square Meter
OPC	-	Ordinary Portland Cement
POFA	-	Palm Oil Fuel Ash
R^2	-	Coefficient of determination

RHA	-	Rice Husk Ash
Rw	-	Sound Reduction Index
SAC	-	Sound Absorption Coefficient
SPL	-	Sound Pressure Level
w/c	-	Water cement ratio
W/mK	-	Watt per meter by Kelvin
XRF	-	X-Ray Fluorescence
11MP	-	Eleventh Malaysia Plan
°C	-	Degree Celsius
α	-	Sound Absorption Coefficient
Ø	-	Diameter

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Bricks are considered an important and strong building material that has been used for many years. Bricks are durable and require low maintenance. Bricks are usually made of clay minerals and are usually used in the construction of building walls around the world. Bricks are also considered as a type of construction material which is in high demand (Rahman *et. al.*, 2014).

Sound absorption properties is one of the properties of brick to be emphasize. In this study, sound absorption test was conducted to study the effect of the replacement material in the brick on the sound absorption coefficient. The primary binder to produce brick and concrete are cement and sand. In recent years, the development of infrastructure has grown rapidly and this has triggered the concrete industry to produce large amounts of cement due to the high demand for concrete as the number of construction projects has increased. However, Portland cement production leads to environmental pollution caused by carbon dioxide emission (Tabassum and Khadwal, 2015).

Nowadays, the use of waste as an additional or replacement material in concrete is gaining popularity primarily to enhance performance, reducing cost and for environmental sustainability. One of the waste used is Palm Oil Fuel Ash (POFA). POFA is a solid waste by-product in the form of ash obtained from the burning of palm oil husk and palm kernel in a palm oil boiler from a palm oil mill (Munir *et. al.*, 2015).

The waste from the burning process is suitable to be used as cement replacement material to improve the properties of mortar or concrete (Zeyad *et. al.*, 2016). The use of palm oil waste from the industry in any composite material helps reduce environmental waste problems.

This study focuses on developing lightweight bricks using waste material and materials with a lower density. EPS was chosen as a replacement material due to its lightweight properties that are capable of reducing the weight of concrete bricks equivalent to its density. Ling and Teo (2012) stated that EPS is polystyrene in raw beads that expands after being steam-heated. EPS is light, has good energy absorbing characteristics and is a good thermal insulator. EPS is light, rigid, possesses good thermal insulation and has high impact resistance. EPS is also safe to be used as it complies with all relevant technical environment standards.

Besides, another reason to use EPS as a replacement material is due to its lower density which is expected to be good for sound absorption some researchers state that the EPS is good in absorbing energy wave. Azkorra *et. al.* (2015) state that porous materials are good for sound absorption.

The purpose of this study is to assess the effectiveness of Palm Oil Fuel Ash (POFA) and expanded polystyrene beads (EPS) in the production of bricks based on its physical and mechanical properties and its suitability as a sound absorption material. POFA is used as a partial replacement of cement while EPS as partial replacement of sand in the mortar mixture.

1.2 Problem Statement

According to Ling and Teo (2012), bricks are widely used in the construction of walls for buildings and are considered one of the most important building materials. The most common bricks used in the construction industry nowadays are clay bricks. However, the production of clay bricks consumes high energy such as the burning of fossil fuels and the ongoing mining of clay soil which is not sustainable for the industry. Due to unsustainable mining, the industry switched to the use of cement bricks. Nevertheless, the production of cement bricks needs a large amount of cement which is not environmentally friendly as the manufacturing of cement consumes a lot of energy and each tonne of cement produced will release approximately one tonne of carbon dioxide (CO_2) into the environment.

Hence in some researches, recycled materials are often used as a replacement or an admixture in concrete or mortar due to the environmental pollution caused by existing materials. According to Alsubari *et. al.* (2016), environmental and greenhouse gas problems are caused by the cement production process which contributes to about 7% of the global CO_2 emission. The Eleventh Malaysia Plan (11MP) declared that the housing sector will be boosted further because more affordable house will be built to meet the need of low-income nation in Malaysia. Besides, more infrastructure facilities such as schools and hospitals will eventually be built. Thus, this will lead to rapid growth in the construction industry and increase the demand for construction materials in Malaysia.

Recycled material that usually used by researches to reduce cement consumption are materials with pozzolanic properties such as Fly Ash, Silica Fume, POFA and etc. Recently, the utilization of pozzolanic materials in cement and concrete has increased considerably due to their diverse benefits such as less cement use, saving production costs, improvement of the durability properties of the concrete and so on. The use of POFA as a pozzolanic material to replace cement is a sustainable alternative (AL-Oqla and Sapuan, 2014) as Malaysia is one of the largest producers in the palm oil industry (Raut and Gomez, 2016). This industry has been generating a great deal of waste which is becoming one of the major contributors to the nation's pollution problem. POFA is produced by the industry and is discharged from palm oil mills. The improper disposal of large quantities of palm oil fuel ash may contribute to environmental problems in future (Megat Johari *et al.*, 2012). According to Rahman *et. al.* (2014), a very significant amount of biomass including empty fruit branches, oil palm shells and POFA are generated every year. It is estimated that 100 million tonnes of solid biomass will be produced by 2020. Approximately four kilograms of dry biomass is produced for every kg of palm oil produced. POFA is a by-product of the palm oil industry and is produced from the burning of empty fruit branches and oil palm shells. POFA is ae highly pozzolanic material which can not only be used as a material to replace cement, but also to increase the compressive strength and durability of concrete. ASTM C61 8-92a has classified POFA in Class C according to it chemical content (Adnan *et. al.*, 2013).

The properties of bricks itself are not only for supporting loads, hence, the elements of contributing to sustainable construction nowadays consists of the use of other materials to replace sand (Ali *et. al.*, 2017). The increasing demands for natural aggregates is posing a major problem too especially to the construction industry in developing areas where manufacturers find it difficult to locate adequate sources of natural aggregate supply (Khalid *et. al.*, 2017). The best alternative which can reduce the usage of natural sand as well can provide lightweight properties to the brick is by replacing the natural sand with Expanded Polystyrene Beads (EPS). Due to it lightweight properties, EPS were primarily used as fine aggregate replacing sand to reduce the weight of the brick.

According to Musab (2016), EPS is lightweight, not harmful to human health and can be found easily. Polystyrene is low in density, lightweight, inexpensive and easy to produce compared to sand. Besides, compared to ordinary bricks, lightweight bricks have some excellent characteristics such as lower density, higher specific strength, better thermal insulation and greater energy absorption which can be obtained by replacing standard aggregate totally or partially with lightweight aggregate (Xu *et. al.*, 2012).

In this modern world, noise from the surroundings is a common problem. Noise is an unwanted sound and high levels of noise can cause sound pollution. This has led to an increasing need for materials that are able to absorb sound to reduce noise. Current sound absorbing materials are made of synthetic, glass and mineral fibres. Glass and mineral fibres can be a risk to human health as they can cause skin problems and respiratory disorders. Kudo and Aizawa (2019) have conducted a study on the behaviour of rock wool in lungs after exposure by nasal inhalation in rats. The thinner and longer the fibre is, the more carcinogenic it becomes. In addition, regarding bio persistence, fibres that remain in the lung tissues for a long period of time without being degraded or transferred are considered to be more carcinogenic. Fibres with a length of 20 µm or those with a long half-life tend to cause fibrosis or cancer because of low degradation in the living body.

Currently, sound absorbing materials used in the construction industry as building materials contain fibrous materials. The group of man-made minerals or vitreous fibres (MMMFs or MMVFs) includes glass wool, rock wool, slag wool, glass filaments and microfibres and refractory ceramic fibres (RCFs). The materials applied in the building industry include asbestos, rock wool and acoustic fibreglass (Vuyst *et. al.*, 1995). However, more attention is being paid to health and safety-related issues because of the potential health risks associated with these fibres. According to the review conducted by Nelson (2013), crystalline silica and asbestos are common minerals that occur throughout South Africa, exposure to either causes respiratory disease. Pulmonary silicosis, the disease most commonly caused by exposure to crystalline silica dust, was described in South African gold miners in the early 1900s, not many years after gold-mining commenced. Currently, South Africa has one of the highest rates of silicosis in the world. This related issue provides an opportunity to find alternative materials to be developed as a replacement material for the absorption of sound.

1.3 Objectives of Study

The objectives of this study are as follows:

(i) To evaluate the physical and mechanical properties of lightweight brick containing EPS and POFA.
(ii) To identify the sound absorption coefficient of lightweight brick containing EPS and POFA.
(iii) To analyse the relationship between the sound absorption coefficient and the properties of lightweight brick containing EPS and POFA.

1.4 Scope of Study

The scope of the study is as follows:

(i) Brick samples measuring 215 mm × 102.5 mm × 65 mm according to BS 4729-1990 and bricks with density below 1680 kg/m^3 were prepared according to ASTM C90-06b.
(ii) Various percentages of EPS were used as sand replacement (0%, 20%, 30%, 40% and 50%) in the samples.
(iii) Various percentages of POFA were used as cement replacement (0%, 5%, 10%, 15%, 20% and 25%) in the samples.
(iv) The properties investigated included density, compressive strength, water absorption and initial rate of water absorption.

(v) The sound absorption of lightweight brick was tested using the impedance tube test according to ASTM E1050 standard for low frequencies (0-1500 Hz) and high frequencies (1500-5000 Hz).

(vi) The bricks were air cured for 7, 28 and 56 days.

(vii) Controlled samples were prepared with 0% EPS and POFA replacement.

(viii) The type of tests and number of samples are stated in Table 1.1.

Table 1.1 : Number of samples prepared for each test

Type of Test	Number of Samples
Density & Compressive Strength	270
Water Absorption	90
Initial Rate of Water Absorption	90
Sound Absorption : Low Frequency	90
: High Frequency	90
Total Sample	630

1.5 Significance of Study

This study was mainly to investigates the ability of lightweight bricks to absorb sound compared to normal bricks as acoustic is one of the important parameter for a building comfort. In present, commercial materials used for sound absorption contain glass fibre or minerals that could be a health risk. Therefore, it is important to find alternative sound absorbing materials. Currently, most studies regarding sound absorption material focused on the preparation of sound absorption panels from waste materials such as natural fibre, fabric waste and agricultural waste. The panels are usually applied as additional component for ceilings and as additional layers for walls. However, studies on sound absorption of the main component of wall which is the bricks and the replacement materials itself are still lacking.

This study is an attempt to identify alternative materials that can be used in the construction industry with its own ability to absorb sound, enhance compressive strength and other physical and mechanical properties of lightweight brick. It is also conducted to investigates the potential use of POFA and EPS for producing an energy saving, sustainable, lightweight and good sound absorbing composite brick as a building material. There are some previous study conducted concrete or brick with

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